AGE DIFFERENCES IN THE CAPACITY OF VISUAL SHORT-TERM MEMORY:

EFFECTS OF STIMULUS TYPE AND INFORMATION LOAD

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ABSTRACT

Leslie Vaughan: Age Differences in the Capacity of Visual Short-term Memory: Effects of Stimulus Type and Information Load
(Under the direction of Marilyn Hartman)

The goal of the current study was to examine age differences in visual information load and visual STM for two types of items, abstract and meaningful, as well as determine the impact of item type and information load on age-related reductions in STM. Two experiments tested the hypotheses that age differences are greater in visual search and visual short-term memory for abstract items, and that information load may not fully explain age differences in visual STM. Age differences in visual search were greater for abstract than meaningful items, but older adults showed equivalent age-related reductions in visual STM for the two classes. Information load was a better predictor of visual STM capacity than item type when we compared the two classes.

CONTENTS

LIST OF TABLES

Table Page

CHAPTER 1

Introduction

The storage component of Baddeley's model of working memory (WM) is generally referred to as short-term memory (STM) **(**Baddeley, 1992). Age differences in the capacity of STM are well documented (Hartman & McCabe, 2003; Verhaeghen, Marcoen, & Goossens, 1993), but the reasons for age-related differences in STM storage are unclear. One explanation is that older adults may be less able to encode a durable representation in STM (Hartman, Dumas, & Nielsen, 2001). The size of age differences in the ability to encode information may further depend on the type of material to be remembered. Myerson, Emery, White, & Hale (2003) found greater age differences on simple span storage tasks in the visual than the verbal domain. Thus, the current set of experiments focuses on storage capacity as a possible locus of age differences in STM, in particular storage in visual STM.

The majority of aging research on storage in STM has focused on the verbal domain, and most of the research on visual STM has focused on the spatial rather than the object domain. A few studies of younger adults have looked within visual STM at capacity for different classes of objects, for instance colors, simple shapes, Chinese characters, random polygons, meaningful objects, and patterns (Alvarez, 2004; Della Sala, Gray, Baddeley, & Wilson, 1999; Vogel, Woodman & Luck, 2001). Within the aging literature, however, no studies within the visual domain have examined how capacity limitations are determined by the characteristics of different classes. An experimental focus on STM for objects, instead of

STM for spatial location, would help to further clarify what is known about capacity limits in visual STM. Different classes of objects may carry different processing ‘loads’ that indicate how complex or difficult they are to process (Alvarez, 2004). Stated another way, limitations in STM in older adults could result from a limited ‘capacity for complexity’ (Baddeley, 1999). This set of experiment focuses on how age may differentially influence the storage capacity of visual STM for different classes of objects that vary in perceptual complexity.

CHAPTER II

Visuospatial Short-Term Memory

The independence of STM systems for verbal and visual information is well-documented in younger adults (Baddeley, 1992; Logie, Della Sala, Wynn, & Baddeley, 2000; Shah & Miyake, 1996). The visual STM system has been further divided into two separate stores for visual and spatial information and labeled visuospatial STM (Baddeley, 2003; Logie, 1995). Within the visual domain, behavioral evidence of dissociations between object and spatial information (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Hartley, Speer, Jonides, Reuter-Lorenz, & Smith, 2001) are corroborated by neuroimaging studies that show distinct neural networks for objects and spatial locations in younger adults (Haxby et al., 1991; Smith et al., 1995).

Smith et al. (1995) reported a double dissociation between STM for objects (irregular polygons) and spatial locations. Varying the location proximity of probes to studied items affected performance in the spatial but not the object task, and varying the shape similarity of the probes affected performance in the object but not the spatial task. Thus, simple storage of non-meaningful objects such as abstract patterns and shapes has been differentiated from simple storage for location, suggesting that these are independent processes.

A double dissociation within visuospatial STM has also been reported for pattern and spatial information (Della Sala et al., 1999). In a selective interference experiment, participants' pattern and spatial spans were measured using the Visual Patterns Test and the

Corsi Blocks Test. In the Visual Patterns Test, participants are presented with matrix checkerboard patterns that are made increasingly difficult by adding random squares to the pattern. Participants mark the squares in an empty grid of the same size. The score is the number of correctly filled cells in the most complex pattern recalled. In the Corsi Blocks Test, the experimenter taps a sequence of blocks. The subject is asked to tap out the same sequence. The sequence length is increased and the subject's spatial span is taken to be the longest sequence in which two out of three sequences are correctly reproduced. Either a visual or a spatial secondary task was interposed between the presentation of the stimulus (a visual pattern in the Visual Patterns Test or a spatial sequence in the Corsi Blocks Test), and the test. Then the pattern or spatial span was redetermined. The tests of STM for abstract pattern and spatial location showed a double dissociation pattern of interference from visual and spatial secondary tasks, evidence that pattern and location are distinct subcomponents of visual STM.

In conclusion, it is known from studies of selective interference that visuospatial STM is independent of verbal STM (Baddeley, 2003; Logie, 1995). It also has distinct subcomponents of object identity and spatial location (Della Sala et al., 1999; Smith et al, 1995). Within the subcomponent of object identity, it is less well-known how different types of visual objects determine the capacity of visual STM.

CHAPTER III

The Capacity of Visual Short-Term Memory

To determine the unit of storage in visual STM, Vogel et al. (2001) explored the capacity limits of visual STM for features or conjunctions of objects. They tested the hypothesis that visual STM capacity is determined by the number of stored integrated object representations rather than the number of features. They based this hypothesis on object-based theories of attention which predict that attention is directed towards integrated objects rather than independent features and on studies showing that if one feature of an object is attended, then all features of that object are available at no additional cost (e.g., Duncan, 1984).

The capacity of visual STM for simple features and conjunctions of features was studied in 16 experiments using a change detection task (Vogel et al., 2001). In the simple feature condition, on each trial participants viewed a briefly presented sample array of 1-12 objects from a single stimulus class (colored squares, letters, or line orientations). In the conjunction condition, participants attended to varying numbers of conjunctions of features (color, orientation, size, and presence or absence of a black gap). After a short delay, a test array was presented that was identical or differed in terms of a single feature of a single item in the array (in the feature conditions), or a conjunction of two features (in the conjunction conditions). They also varied the number of items in each array (the set size). Visual STM capacity was measured by assuming that accuracy would be perfect for set sizes within the capacity of visual STM , but would decline systematically as the set size exceeded visual STM capacity. The capacity of visual STM was calculated using a quantitative approach developed by Pashler (1988). If k is the memory capacity, S is the set size of the array, H is the observed hit rate, and F is false alarms, then $k = [S \times (H - F)] / (1-F)$. If a participant can hold k items in memory out of an array of S items, the item that changed should be one of the items being held in memory on k/S trials, leading to correct performance on k/S of the trials on which an item changed.

In support of object-based theories of attention, Vogel et al. (2001) found that the units of storage of visual STM are integrated object representations rather than independent features. They determined that the capacity of visual STM is 3 to 4 objects, regardless of stimulus class or condition. For instance, at a display size of 4 objects, observers could retain 16 features in the conjunction condition as well as they could 4 features in the feature condition. This provided evidence that conjunctions of features can be remembered as accurately as single features.

In contrast to Luck and colleagues, Alvarez & Cavanagh (2004) found that the capacity of visual STM was set both by an empirically determined visual information load and by the number of objects. In other words, the total information load and the number of objects interact to impose capacity limits on visual STM. Alvarez and Cavanagh conceptualized the visual information load of a particular object as the amount of visual detail stored for that object, and measured it with a visual search task. They reasoned that the more visual information that must be analyzed per object, the slower the visual search rate. Alvarez & Cavanagh (2004) hypothesized an inverse relationship between visual search rate and memory capacity $I = C/N$, such that I, or the information per item estimated with the visual search task (search rate), equals *C*, the capacity of visual STM, divided by *N*, the number of objects in the array. They determined the search rate individually for each participant for each of six stimulus classes (colors, random polygons, Snodgrass line drawings, Chinese characters, shaded cubes, and letters) by calculating the slope of the line relating the target present reaction time to the number of targets (4, 8, or 12) in the visual search test display. To estimate memory capacity of objects for each of the above six stimulus classes, a change detection task with varying display sizes (1, 3, 5, 7, 9, 11, 13, or 15) was used. For each stimulus class, half of the number of objects in the array yielding 75% correct performance was used to estimate memory capacity. These estimates ranged from 1.7 for shaded cubes to 4.4 for colors, with decreased capacity for abstract (random polygons, Chinese characters, shaded cubes) versus meaningful objects (colors, Snodgrass line drawings, and letters). In summary, capacity was not constant across the range of visual materials tested, and an inverse relationship between visual information load and capacity was found. The greater the item information load (as indicated by a slower search rate), the fewer objects from that class were remembered. Alvarez and Cavanagh (2004) concluded that STM capacity varies across different stimulus classes, with more capacity allocated to perceptually more complex stimuli, but that maximum capacity is limited to four or five items for any class of objects.

Alvarez and Cavanagh (2004) provided two explanations for how visual STM capacity can be determined by the complexity of the object, but also by the number of objects (Vogel et al., 2001). These explanations are dependent upon differences in stimuli between the two experiments. First, there might be separate visual STM stores for features of an object such as size, color, and orientation that each have their own capacity (Wheeler &

Treisman, 2002). Capacity for conjunctions of features would be as high as capacity for individual features, because reaching the capacity limit for one feature, for instance orientation, would not prevent remembering information about another feature, for instance color. This pattern of results was demonstrated by Vogel et al. (2001), who used simple stimuli such as colored squares, lines, and orientations. This explanation could also account for the results of Alvarez and Cavanagh (2004), who obtained reduced capacity for items with multiple values on single dimensions (for instance multiple orientations) using complex stimuli such as Chinese characters and random polygons. Secondly, Alvarez and Cavanagh suggest that the minimal representation of an object is defined by an obligatory set of ‘core’ features that are always encoded regardless of the task demands. The features in Vogel et al.’s stimuli could all be in this core set. This would explain how conjunctions of features did not increase the information load of the objects in Luck et al.’s experiments. However, the more complex stimuli such as Chinese characters and irregular polygons used by Alvarez & Cavanagh may have required additional encoding and capacity beyond the core set.

Eng, Chen & Jiang (2005), questioned whether the correlation between visual search and change detection performance found by Alvarez & Cavanagh was due to memory or perceptual encoding. The researchers used a visual search task to measure perceptual complexity and a change detection task to measure visual STM, manipulating stimulus type and memory set size. In addition, they varied the duration of the sample display (500, 1000, or 3000 ms) in the change detection task. They found by varying the presentation duration of the sample display, that information load was a better predictor of visual STM capacity at shorter durations. Information load did not have a constant relationship with visual STM capacity. As the duration of the sample display increased (30% with a study array duration of

3000 ms or longer), information load accounted for a smaller amount of variance in STM capacity In agreement with the results of this study, the high correlation found by Alvarez & Cavanagh (2004) using a 500 ms duration for the sample change detection display also suggests that at shorter durations, performance on the memory array may additionally be limited by perceptual encoding. In other words, if participants failed to perceive what is in the memory display, they would not be able to detect changes, because the information was never encoded into visual STM.

In conclusion, the capacity of visual STM is set both by the number of objects (Vogel et al., 2001) and the perceptual complexity of the object (Alvarez & Cavanagh, 2004). Visual STM consists of various classes of objects that have different processing loads, including meaningful line drawings, unnameable shapes, abstract patterns, and faces to name a few (Alvarez & Cavanagh, 2004; Eng et al., 2005). Moreover, there is an inverse relationship between information load, or complexity, and STM capacity. Additionally, the strength of this relationship is dependent upon the amount of time allowed to encode the memory display. The correlation between information load and STM capacity increases when the encoding time for the memory array is short (Eng et al., 2005). These results raise interesting questions about how different classes of objects set the capacity limits of visual STM. For instance, higher loads and decreased capacity are observed for unnameable shapes and abstract patterns such as Chinese characters (Alvarez & Cavanagh, 2004). The relationship between visual information load and the capacity of STM is one that will be explored in this set of experiments.

CHAPTER IV

Age Differences in Verbal and Visuospatial Short-Term Memory

Age differences in verbal WM are well-established (Salthouse, 1996; Verhaeghen, Marcoen, & Goossens, 1993). Research on the storage systems in the WM model have emphasized the verbal component (Baddeley, 2003). Only a handful of studies have compared age differences in spatial and verbal STM, and none have compared age differences in spatial and object STM. Most of these aging studies have used simple span tasks to measure the amount of temporary information storage in memory, and have analyzed memory for digits and locations (Myerson, Emery, White, & Hale, 2003), letters and locations (Jenkins, Myerson, Joerding, & Hale, 2000; Hale & Myerson, 1996) and objects and locations (Hartley, Speer, Jonides, Reuter-Lorenz, & Smith, 2001). Visual STM is more age sensitive than verbal STM in these studies, at least for spatial location (Hale & Myerson, 1996).

Building on results that older adults had lower spatial spans than younger adults but similar digit spans (Hale & Myerson, 1996), Myerson et al. (2003) directly compared normative data from the Wechsler Memory Scale (WMS-III) on measures of forwards and backwards spatial span to forwards and backwards digit span. A sample of more than 1000 adults matched to the normal population on sex, education level, race and ethnicity, and geographic region were sampled from age 16 to age 89. The forwards version of the spatial span task was the Corsi Blocks Test described earlier. In the backwards version of the spatial span task, participants recalled the locations in reverse order. In the Digit Span task, subjects repeated a series of spoken digits in the order presented or in reverse order. Scores on the spatial span subtests of older adults were significantly lower than younger adults', and the slope of the regression of spatial span on age was significantly more negative than the corresponding slope for digit span. As age increased, spatial span decreased at a greater rate than digit span.

The findings of Park et al. (2002) regarding STM corroborated those of Myerson and colleagues. They examined age differences in both STM and WM in the visuospatial and verbal domains. Their results indicated greater age differences in STM in the visuospatial than the verbal domain. Park and colleagues also used a large sample (345 people), ranging in age from 20 to 92 years, to model memory across the life span. Verbal and visual span tasks were the same as Myerson et al (2003), forward and backward digit span and forward and backward Corsi blocks.

This pattern of age differences was also replicated by Jenkins et al. (2003), who compared location and letter span in older and younger adults. Younger adults had greater location spans (M = 7.48) than letter spans (M = 6.46), but older adults showed no difference between them (location spans, M = 4.62, and letter spans, M = 4.39). These results indicated smaller memory spans overall for older adults, and larger age differences in STM for locations than for letters.

Further support for greater age differences in the visual than the verbal domain comes from experiments that measure processing speed. Jenkins et al. (2000) compared younger and older adult performance on visuospatial processing speed tasks that did not have a memory requirement such as line length discrimination and shape classification. They found greater age differences in the visuospatial than in the verbal domain, indicating domain specific slowing. Chen, Myerson, & Hale (2002) used visuospatial processing speed tasks in both the object and spatial domains. They found that younger adults showed a stronger correlation between reaction times on tasks that assessed the same domain (either visual or spatial), whereas older adults did not, indicating less efficient perceptual processing in older adults. This further suggests that age differences may be greater in the visuospatial domain.

Results from comparisons of age differences in verbal and visuospatial WM may not be as conclusive as those from STM. Using the same tasks as Myerson (2003), Park et al. (2002) found limited evidence for greater decline in the visuospatial than the verbal domain, whereas Myerson (2003) found significant evidence for greater decline in the visuospatial than the verbal domain. Park completed a family-wise correction for the number of statistical tests performed, whereas Myerson did not, perhaps leading to the discrepancy in results. In general, findings from studies of aging comparing verbal and visual STM consistently show age-related differences in STM (Jenkins et al., 2003; Myerson et al, 2003), whereas findings from studies of aging comparing visual and verbal WM and aging do not (Park et al., 2002).

Few behavioral studies have examined the effects of aging on subcomponents of visual WM, and none have looked specifically at storage in visual STM. In the handful of studies that have explored age differences within visual WM, only one has compared object and spatial location. Hartley et al. (2001) dissociated WM for verbal information, visual objects, and spatial location in three experiments. Most relevant to this discussion, Experiment 2 tested WM for object identity and spatial location in a 1 – back task using a selective interference paradigm. Non Arab-speaking participants determined whether Arabic characters presented one at a time on the circumference of an imaginary circle matched the previous item in two conditions, object identity or spatial location. Visual similarity of Arabic characters (similar or dissimilar) and spatial location proximity (match, near, far) were manipulated. Visual similarity of characters was expected to interfere with the ability to match the identity of the probe to the item 1-back and proximity of Arabic characters to the spatial location of the probe was expected to interfere with the ability to match the probe location to the location of the item 1-back.

In each age group, visual similarity affected only memory for object identity and physical proximity affected only memory for spatial location. This indicated that younger and older adults share a double dissociation of WM for object identity and spatial location and that the two systems remain distinct in old age. Evidence also indicated that older adults may be less able to encode object identity than younger adults (Hartley et al., 2001). Age differences were greater for object identity (Arabic characters) than location. Lower performance on the object task was attributed to less effective encoding of objects by older adults. Thus, it appears that in this task, older adults have more difficulty encoding objects that are non-meaningful (Arabic characters) than younger adults.

In conclusion, the focus of aging studies of visual STM has been two-fold. The first focus has examined age differences in visual and verbal STM (Myerson et al., 2003; Jenkins et al., 2000). These studies have compared both simple and complex span measures in older and younger adults, finding greater age differences in spatial and location spans than digit or letter spans (Myerson et al., 2003; Jenkins et al., 2000). This evidence favors greater age differences in the visuospatial than the verbal domain. The second focus has examined age differences within the visuospatial domain (Hartley et al., 2001). Within the visuospatial domain, the effects of age may differ for tasks that measure spatial versus visual stimuli.

These have not been tested directly in visual STM, but a few studies have examined age differences within visual WM. Hartley et al. (2001) found greater age differences for object identity (Arabic characters) than location on a 1-back task. Additionally, older adults demonstrated decreased WM accuracy for Arabic characters than younger adults. This suggests that the type of stimuli may differentially influence older adults' memory accuracy. Greater age differences in the non-memory visuospatial domain may also support the above conclusion (Chen et al., 2002; Jenkins et al., 2000). In conclusion, these studies provide evidence that age differences in STM are greater in the visuospatial than the verbal domain, and that there may be differential effects of age within the domain of visual STM. The following section considers explanations for the pattern of age differences in visual STM.

CHAPTER V

Visual Search and Aging

The visual search task is used to estimate the search rate, or the information load of a particular object or class of objects. For example, visual search rate increases as the information content of the object increases. Visual search is an attention-demanding task in which participants locate targets among distractors. It involves rapid shifts in the distribution of attention among objects and the comparison of one or more targets held in STM (Woodman & Luck, 1999). The visual search rate is an index of the processing rate or information load of a visual object, and a measure of the amount of detail encoded Alvarex & Cavanagh (2004).

Visual search rate also is affected by group differences such as age. A number of factors increase age differences in visual search. These include the type of search (feature or conjunction), the size of the display, the presence or absence of a target, and the similarity of target and distractors. In feature search tasks, the target varies from the distractors by one feature, such as color. In conjunction search, the target and the distractors vary in how multiple features are combined, for instance a red X among green Xs and red Os. Age differences in visual search rates are usually greater in conjunction than feature search, and increase with display size (Hommel, Li, & Li, 2004). Increased visual similarity of the display also leads to longer latencies in older adults (Scialfa, Esau, & Joffe). All of these effects are generally more pronounced in older adults on target absent trials (Hommel et al., 2004).

The generalized slowing hypothesis was tested to explain age differences in visual search due to type of search (feature or conjunction), visual similarity, and display size (Madden, Whiting, Cabeza, & Huettel, 2004; Scialfa et al, 1998). This is the hypothesis that a common factor, perceptual speed, accounts for the equivalent slowing of cognitive processes (Salthouse, 1996). Brinley plot transformations of the data were used to test this hypothesis. For example, Scialfa (1998) found greater age differences in RTs in visually similar displays than in visually dissimilar displays with increasing array sizes, suggesting greater susceptibility to interference. After Brinley plot analysis, generalized slowing could account for this effect. Madden et al. (2004) found that older adults benefitted from top-down attentional guidance in a visual search task as much as younger adults, but that bottom-up attentional processes are slowed. However, these results could also be accounted for by generalized slowing after Brinley plot analysis.

It is also possible that age differences in visual search may vary according to the stage of processing. Different stages of visual search were examined by Verhaeghen (2002) in a time-accuracy study of older and younger adults. The visual search arrays consisted of four letters with a new randomized target on each trial. The target was displayed for 1000ms but the search array display time was variable (30, 40, 60, 80, 100, 1150, 200, 300, 500, 1000 ms). A time accuracy function with parameters *a* (time needed to start the encoding process), *b* (how fast performance increased once processing started), and *c*, (the asymptotic accuracy of the function) was estimated. As indicated by age differences in parameters *a* and *b* but not *c*, encoding of older adults started after a longer delay and developed more slowly than younger adults, but the level of asymptotic performance was not reliably smaller than younger adults because of ceiling effects. In addition, he found the greatest age differences in parameter *a*, the time needed to start encoding the visual search display. Verhaeghen (2002) suggested that these results may reflect age differences in early stages of processing such as visual perception.

Hommel et al. (2004), corroborated the idea that older adults are less able to extract information from a visual display, but attributed this to increased ‘cautiousness’ in decision-making processes associated with terminating a search. Based on greater age differences in target absent trials with increasing numbers of distractors, they hypothesized that older adults spent more time sampling ‘sensory evidence’ from the display to achieve a reliable signal to noise ratio in the presence of increased age-related cortical interference or ‘noise’.

In conclusion, age differences in visual search have been established for conjunctions of features, but not for different classes of visual stimuli that vary in complexity. The source of age differences in visual search may be found in the early stages of visual processing, such as attention-based visual perception (Verhaeghen, 2002). Alternatively, age differences in perception have been explained by generalized slowing (Madden et al., 2004; Scialfa, 1998). Possible age differences in visual search for objects with increased information loads may ultimately be explained by different component processes such as perception or the subsequent attentional binding of percepts.

CHAPTER VI

Experiment Overview and Hypotheses

This experiment was designed to examine the effects of aging on the relationship between information load and STM capacity. The goals of the current study were to compare age differences in visual STM for meaningful versus abstract items and to assess the contribution of the visual information load of the stimuli to these age differences. In addition, we wanted to know if age differences in visual STM would be better explained by the information load of the item or the type of item. Towards this end, we measured information load with a visual search task and STM with a delayed match to sample (DMTS) task. Overall, we wanted to see if younger adults would show an inverse relationship between information load and STM capacity, and if older adults would demonstrate the same pattern.

Experiments 1 and 2 were designed to examine the relationship between age, information load, and STM capacity. There were two goals of the visual search task used in Experiment 1. The first goal was to compare age differences in RTs and search rates for the two classes of items. The second goal was to establish the search rate, or information load, for items within the two classes, meaningful and abstract. In the second experiment, younger and older adult performance was compared on a STM task using the same items. In order to assess the contribution of both item load and item type to STM capacity, a subset of abstract and meaningful items with overlapping search rates in younger adults (older adults did not have an equivalent subset) were compared in both age groups. The overlapping subset consisted of abstract and meaningful items whose mean search rates did not differ. In addition, items from within each class were divided equally into low, medium, and high load types, separately for both age groups. The corresponding accuracy for these four groups was examined to see if an inverse relationship between information load and STM exists within classes of meaningful and abstract items.

We hypothesized that meaningful items may have a lower information load than abstract objects, and therefore be easier to attend and remember, because top-down processing could facilitate perception and thus reduce the impact of perceptual complexity for meaningful objects. Abstract items may require additional binding above and beyond a core set of features, as Alvarez & Cavanagh (2004) suggested, making them more difficult to attend and remember. In each case, there should be reduced STM for objects with greater information loads, because they are more difficult to bind or encode. Items with a greater information load take may take longer to bind in visual search, and items that take longer to bind in visual search might be more difficult to encode into STM. In addition, there may be greater age differences for items with higher information loads, both in visual search and in DMTS, because of age-related decreases in perception and STM. The following experiments were designed to examine the contributions of age, information load, and item type to visual search and visual STM performance.

CHAPTER VII

Experiment 1

Experiment 1 used a visual search task to calculate search rates, or reaction time as a function of display size, for two classes of objects: abstract designs and meaningful line drawings of objects. Our goals included: 1) comparing the information load of abstract and meaningful classes of stimuli, 2) comparing age differences in search rates for abstract and meaningful items, and 3) establishing a set of abstract and meaningful stimuli that have overlapping search rates in younger adults and older adults.

To measure the information load of classes of visual stimuli, we used a visual search task similar to the one used by Alvarez & Cavanagh (2004). On each trial, a briefly presented target was followed by an array of 4, 8, or 12 items from the same stimulus class as the target. The target was present on half the trials, and participants indicated as quickly as possible whether the target was present or absent. The visual search rate was estimated by taking the slope of the function relating the target present reaction time to the number of items in the display. Search rates were calculated both for each individual (separately for abstract and meaningful items) and for each item (separately for young and old).

In Experiment 1, we expected to find increased search rates for abstract versus meaningful items (Alvarez & Cavanagh, 2004), and for older versus younger adults (Hummel & Li, 2004). Additionally, greater age differences in search rates for abstract than meaningful stimuli were predicted, because of the higher binding requirement for items with higher information loads. Additionally, we expected to be able to establish a set of abstract and meaningful stimuli with overlapping search rates for both age groups.

Methods

Participants. Participants included 36 younger and 35 older adults (see Table 1).Younger adults were undergraduates at the University of North Carolina at Chapel Hill who participated in this experiment in exchange for credit in an introductory psychology course or for pay. Older adults were members of the community recruited through local advertisements and paid ten dollars per hour for their participation.

Eligibility requirements for all participants included normal or corrected-to-normal vision, and reports of good health to excellent health on a health screening questionnaire (see Appendix A). Participants were excluded if they reported a history of neurological or psychiatric disorders, learning disability, major illnesses that may affect their cognitive function, or use of psychoactive medications. Participants were also excluded if English was not their native language. All participants were given the Beck Depression Inventory-II (BDI-II) (Beck, Steer, & Brown, 1996; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961), the Beck Anxiety Inventory (BAI) (Beck, Epstein, Brown, & Steer, 1998; Beck & Steer, 1990), and the Amnart Vocabulary Test (Grober & Sliwinski, 1991). The data of any participants who scored above the normal to mild clinical range of 0-13 on the BDI-II and/or above the normal to mild clinical range of 0-9 on the BAI were excluded. Older adults were screened using the Mini-Mental Status Exam (MMSE, Folstein, Folstein, & McHugh, 1975) and obtained a score of at least 28 out of 30 to be included in the study. Five younger adults and 4 older adults were replaced for scores above the cutoff on the BDI, and 4 younger adults and 3 older adults were replaced for scores above the cutoff on the BAI. Two older adults were replaced for scores below the cutoff on the MMSE.

Design. Older and younger adults completed a visual search task. Experiment 1 used a 2 (age) x 2 (item type) x 3 (array size) mixed factorial design with item type and array size as within subjects factors and age as a between subjects factor. Two classes of items, meaningful line drawings or abstract designs, were presented in the visual search array. Array sizes of 4, 8, and 12 items were tested.

Item types (abstract and meaningful) were blocked separately, as were array sizes (4, 8, and 12). For each item type (in each of the three array sizes), there were 13 blocks of 15 trials, resulting in a total of five hundred eighty-five trials per item type. Each block had a single target. The target was present in the array on half of the trials. The order of trials within blocks was randomized separately for each participant. The order of blocks was randomized for each participant. The order of conditions (item type and array size) was counterbalanced for each participant.

Stimuli. Items consisted of two different types, meaningful line drawings and abstract designs. The meaningful line drawings were from the Snodgrass and Vanderwart (1980) set (see Figure C1). The abstract designs were non-nameable items that were either adapted or used in the original from the Salthouse and Babcock Perceptual Comparison Test (1991) and consisted of from 2 to 5 lines (see Figure CII). Adapting the abstract stimuli consisted of either removing or adding single lines using Adobe Photoshop 5.0 (Adobe Systems, Inc). The empirical criteria for choosing the abstract stimuli to use are described below. Dimensions of line drawings from both classes were 4.5cm x 4.5cm. All line drawings were black on a white background. Stimuli were presented in randomized positions on a 4 x 4 grid of dimensions 18cm x 18cm centered on the computer screen.

Through extensive pilot testing with younger adults, a group of 13 stimuli from each class that demonstrated partially overlapping RTs in visual search at array size 8 were chosen (see Appendix C). For instance, the results of pilot data showed that selected meaningful stimuli yielded a range of RTs from 400-900 ms. Selected abstract stimuli yielded a range of RTs from 600-1300 ms. Six stimuli from each type had overlapping RTs from 600-900 ms (see Table 2).

Procedure. On each visual search trial, a target was presented at the center of the computer screen for 500 ms, followed by a 900 ms blank interval, then by an array of 4, 8, or 12 items. The experimenter demonstrated a sample and participants completed three practice trials before beginning the test. Participants were informed that they should try to find the target object in the subsequent display. Participants responded by pressing one of two buttons on a button box to indicate presence or absence of the target in the display. Both accuracy and speed were emphasized. Participants received a 10 s break every block and a longer, untimed break after 6 blocks. During the latter break, the Amnart Vocabulary Test (Grober & Sliwinski, 1991) was administered. On this test participants were asked to read aloud a number of words with irregular pronunciations as an assessment of verbal intelligence. Participants were debriefed following testing and any questions were answered. Each session included both Experiments 1 and 2, and tested one item type. Each participant was tested individually for two sessions lasting 1.5 to 2 hours. The second session took place within 10 days of the first.

Results

Exclusion criteria for each participant included a minimum accuracy of 90% at the smallest array size. These criteria resulted in the exclusion of 2 younger adults and 3 older adults. All reaction times above and below 2.5 standard deviations from the mean were trimmed to remove outliers. Less than 2% of RTs were excluded for younger and less than 2% of RTs were excluded for older adults. Two measures of performance, the mean correct raw RT, and the slope of the function relating the mean correct raw RT to array size for each individual in each class as well as for each item in each class were analyzed. The slope (analogous to the visual search rate) was the primary measure of information load. It represents the difficulty of finding a target in an array as the array size increases. The slope was estimated individually for each participant and each item from the linear regression between RTs for target-present trials and the display size. The target present responses represent the information load of the target item, and thus are the main focus of these analyses. These regressions typically accounted for greater than 95% of the variance, indicating that the functions were linear.

Reaction times. Consistent with recommendations for analyzing data that are not compound symmetric, i.e. violate the assumption of equal residual variance across repeated measures (Tabachnick & Fidell, 2001), a 2(age) x 2(item type) x 3(array size) repeated measures MANOVA was conducted on the correct yes RTs from the visual search task. Table 3 shows RTs by age group and conditions. There was a significant effect of item type, $F(1, 69) = 471.19$, $MSE = 36022.03$, $p < .0001$, $\eta^2 = .87$. Overall, abstract items (M = 1196.5, SD = 291.3) were more difficult to search for than meaningful items (M = 798.9, SD = 171.2). The main effect of array size also reached significance, $F(2, 138) = 264.85$, MSE = 21450.43, $p < .0001$, $\eta^2 = .89$. RTs increased as array size increased. The two-way interaction between item type and array size was significant, $F(2, 138) = 137.75$, $MSE = 8467.51$, $p < .0001$, $\eta^2 = .80$. With increasing array size, the mean increase in RTs for abstract items (616.6 ms) was greater than for meaningful items (256.9 ms).

As expected, there was a significant effect of age, $F(1, 69) = 27.50$, $MSE = 208098.04$, $p < .0001$, $\eta^2 = .27$, indicating better overall performance by younger adults. There was also a significant interaction between age and item type, $F(1, 69) = 39.18$, $p < .0001$, $MSE = 36022.03$, $\eta^2 = .36$. The difference in RTs between age groups was greater in the abstract condition ($M = 347.3$ ms) than the meaningful condition ($M = 116.7$ ms). The interaction between age and array size was also significant. As array size increased, older adults took more time to respond, $F(2, 138) = 4.40$, $MSE = 21450.43$, $p = .02$, $\eta^2 = .12$. Lastly, the three-way interaction between age item type, and array size, was significant, $F(2, 138) = 9.64$, $MSE = 8467.51$, $p = .0002$, $\eta^2 = .22$. In the abstract condition, as array size increased, the mean increase in RTs was greater for older adults (720.3 ms) than younger adults (515.7 ms), $t(69) = 3.62$, $p = .001$.

Slopes. The search functions relating RTs to array size for correct responses to target present arrays were analyzed in a 2(age) x 2(item type) repeated measures ANOVA. Table 4 shows the slopes by age and conditions. There was a main effect of item type, $F(1, 69) = 229.8$, $MSE = 314.38$, $p < .0001$, $\eta^2 = .77$. Slopes in the abstract condition were steeper ($M = 77.3$, $SD = 29.1$) than in the meaningful condition ($M = 32.1$, $SD = 15.3$).

There was significant main effect of age, $F(1, 69) = 8.53$, $MSE = 808.51$, $p=.005$, $\eta^2 = .11$. Overall, slopes for older adults ($M = 61.7$, $SD = 25.9$) were greater than younger adults ($M = 47.7$, $SD = 18.5$). The interaction between age and item type was also significant, $F(1, 69) = 15.27$, $MSE = 314.38$, $p = .0002$, $\eta^{2=}$ .18. Follow-up tests showed no significant age differences in slopes for meaningful items, $t(69) = .63$, $p > .05$, but age difference in slopes for abstract items were significant, $t(69) = 3.97$, $p = .0002$. *Subsets.* A subset of meaningful and abstract items with overlapping search rates in younger adults were established in Experiment 1 for further analyses (see Table 5). Six meaningful ($M = 36.5$, $SD = .80$) and 2 abstract ($M = 33.69$, $SD = .76$) items had mean slopes that did not differ, $t(70) = 1.27$, $p = .21$. The range of slopes was 19.50 to 50.17 for meaningful items and 22.75 to 44.63 for abstract items.

Discussion

The primary goal of the visual search task was both to determine and compare the information load of two classes of items, abstract and meaningful, in younger and older adults, so that we could later examine the relationship between information load and STM accuracy (using the results from Experiment 2). The visual search rate represents the amount of time required to process each item in an array. This rate of processing is sensitive to the additional amount of visual information that must be encoded and compared for each new item in the display, and therefore indexes the amount of visual information per item (Alvarez & Cavanagh, 2004). In line with the above, we hypothesized 1) that abstract items would have a higher cognitive load than meaningful items, and 2) that greater age differences would be found for abstract than meaningful items.

In support of our first hypothesis, we found that overall, abstract items had a higher information load (steeper slopes) than meaningful items. Our second hypothesis was also supported. We found that the difference in search rate between abstract and meaningful items was greater for older adults due to the greater difficulty of the abstract items for the latter age group. Our results concur with others who have found overall age differences in visual search that increase with array size (Hommel et al., 2004), and increase with the complexity of the target (i.e. conjunction versus feature search) (Scialfa et al., 1998).

The source of the greater information load of abstract items is attributed to their perceptual complexity (Alvarez & Cavanagh, 2004; Eng et al., 2005). Certain types of stimuli have a higher binding requirement (Wheeler & Treisman, 2002). The abstract items that we used fit this description because they have multiple same-size line segments with multiple orientations. Assuming that it takes attention to bind a percept, forming a representation of an abstract item makes more demands on perception and attention than forming a representation of a meaningful item, because the latter is supported by long-term visual memory representations of objects. In other words, less binding may be necessary for meaningful items, because stored memories that match them are already bound.

The source of age differences in visual search has been attributed to early attention-based visual perception of the items in the search display (Verhaeghen, 2002). Along similar lines, we favor the explanation that the greater perceptual and attentional demands of binding an abstract line drawing during visual search increased age differences in visual search. Increasing the perceptual complexity of the task resulted in greater age differences for abstract (1.40 times) than meaningful items (1.07 times).

In Experiment 1, we found an increased information load for abstract items, and greater age differences in information load for abstract items. In Experiment 2, we wanted to see if the pattern of age differences found in visual search would be replicated in a STM task. In other words, would greater age differences in visual search for abstract items be reflected in greater age differences in STM for abstract items? Experiment 2 examined STM accuracy for the same abstract and meaningful items as Experiment 1, and used the same participants.

CHAPTER VIII

Experiment 2

Experiment 2 assessed the effects of age and item type on STM performance in a Delayed Match to Sample (DMTS) task. Our goals included: 1) comparing age differences in STM accuracy for items from abstract and meaningful classes, 2) comparing intra-class differences in accuracy for items with low, medium, and high load, and 3) comparing subsets of abstract and meaningful items matched for load on accuracy. Though the intention was to analyze matched subsets for both age groups, these subsets of items were matched and analyzed in younger adults only because there were no overlapping subsets of abstract and meaningful items in older adults.

The version of the Delayed Match to Sample (DMTS) task used in this experiment is a simple storage task that involves the simultaneous presentation of five stimuli followed by an unfilled delay and a single-item recognition memory test. The dependent variable, proportion correct (accuracy), was used as the measure of STM capacity.

In Experiment 2, we first expected to find higher accuracy for meaningful than abstract items. Second, we predicted that younger adults would have higher overall accuracy than older adults. Third, we predicted greater age differences for abstract items. By analyzing a subset of meaningful and abstract items that were matched on information load in younger adults, we also expected to disentangle the contribution of information load and item type tomemory accuracy. We reasoned that if accuracy for abstract items in the matched subset was lower than accuracy for meaningful items in the matched subset, the type of item would explain decreases in STM performance above and beyond information load. We hypothesized that in addition to information load, abstract or meaningless items might explain decreased performance. In addition, we wanted to determine if an inverse relationship between information load and STM capacity existed within types of items. We sub-divided each type into equal numbers of items with low (4 items), medium (5 items), and high (4 items) loads, and examined the relationships between load and accuracy, separately for young and old. We did not have a prediction about how the pattern of performance might differ with respect to item type, but we did predict that age differences in STM would be greater for abstract items.

Method

Participants. The same participants that completed Experiment 1 were tested in Experiment 2 during a second testing session that took place within 10 days of the first.

Design. Older and younger adults completed a Delayed Match to Sample (DMTS) task. A 2 (age) x 2 (item type) mixed factorial design with item type as a within subjects factors and age as a between subjects factor was used. Two classes of items, either meaningful line drawings or abstract designs from Experiment 1 were presented. There were 13 items in each condition.

Item type conditions were blocked separately. In each condition, abstract or meaningful, there were 6 blocks of 13 trials. The target item changed on each trial, occurring once in each block. In each studied array, 1 target item and 4 randomly selected items were presented, and on each test array 1 studied target item and 2 foils were presented. Foils were comprised of randomly selected items from the items that were not present in the studied array. Individual trials were randomized for each participant. The order of blocks was randomized for each participant. The order of item type was counterbalanced for each participant.

The selection of study time was determined in pilot testing. The presentation time of the studied array for both age groups was the time needed for older adults to perform just above chance at a 0 ms delay between study and test. The delay interval used is common in the literature on visual STM.

Stimuli. The same abstract designs and meaningful line drawings used in Experiment 1 were used in Experiment 2.

Procedure. Each trial in the DMTS task began with a warning cross. This was followed by the presentation of a 5 item study array lasting 1500 ms, and a 500 ms delay interval. The study arrays were arranged in 2 rows centered in the middle of the screen. The first row had 2 items and the second row had 3 items. The unfilled delay interval was followed by a test array of 1 object from the studied array and 2 foils in a vertical arrangement. Participants were asked to indicate the single probe item in the test array that was present in the studied array. Participants responded by touching the probe item on the touch screen monitor.

The experimenter demonstrated a sample and participants completed three practice trials before beginning the test. Accuracy was emphasized. Participants received a 10 s break every block and a longer, untimed break after 6 trials. After participants completed all blocks, the Beck Depression Inventory-II (Beck, Steer, Brown, 1996; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) and the Beck Anxiety Inventory (Beck, Epstein, Brown, & Steer, 1988; Beck & Steer, 1990) were administered. Subjects were debriefed following testing, and questions were answered. All participants were given referral information for any mental health concerns. Each session included both Experiments 1 and 2, and tested one item type. Each participant was tested individually for two sessions lasting 1.5 to 2 hours. The second session took place within 10 days of the first.

Results

Exclusion criteria for each participant in each condition included a minimum accuracy cutoff of 40%, just above chance performance of 33%. These criteria resulted in the exclusion of 3 younger adults and 4 older adults.

First, we examined the effect of item type and age on STM. Next, we compared subsets of items with overlapping slopes from younger adults on accuracy, to see if item type might explain STM performance above and beyond information load. Last, within each type, we ordered the items from lowest to highest according to slope. Starting with the lowest, we divided the items into low (4 items), medium (5 items), and high (4 items). This process was completed separately for younger and older adults (since the order of these items was not the same for both age groups). We then analyzed accuracy separately in young and old for the three load types to see if an inverse relationship between information load and STM accuracy held within each class.

A 2(age) x 2(item type) repeated measures ANOVA was performed on DMTS accuracy. Table 6 includes accuracy by age and condition. The main effect of item type was significant, $F(1, 69) = 165.59$, $MSE = .005$, $p < .0001$, $\eta^2 = .71$. Performance on abstract items ($M = .59$, $SD = .08$) was less accurate than performance on meaningful items ($M = .74$, $SD = .10$).

As expected, there was a significant main effect of Age, $F(1, 69) = 7.63$, $MSE = .010$, $p = .007$, $\eta^2 = .10$. Overall, older adults ($M = .64$, $SD = .10$) were less accurate in the DMTS task than younger adults ($M = .69$, $SD = .08$). The interaction between age and item type did not reach significance, $F(1, 69) = .65$, $MSE = .005$, $p = .42$, $\eta^2 = .009$. The difference in accuracy on performance between abstract and meaningful items was similar for both age groups.

A subset of meaningful and abstract items with overlapping slopes identified in Experiment 1 was analyzed on DMTS accuracy in younger adults to answer the question of whether item type predicts accuracy above and beyond load. A one-way ANOVA showed no differences in the overlapping subsets on accuracy, $F(1, 35) = 2.00$, $p = .17$. Accuracy for abstract items ($M = .80$, $SD = .10$) was no different from meaningful items ($M = .76$, $SD = .14$). Though there were a limited number of items in the abstract subset, this result provides additional support for the hypothesis that STM capacity for meaningful and abstract items is determined by information load, and not by the type of stimulus per se.

We also examined correlations between slope and accuracy by item type to further explore the relationship between load and STM capacity. For younger adults, the correlation between slope and accuracy in the abstract condition was non-significant, $r = -.23$, $p = .17$, and the correlation between slope and accuracy in the meaningful condition was also non-significant, $r = -.11$, $p = .53$. For older adults, the correlation between slope and accuracy in the abstract condition was significant, $r = -.40$, $p = .02$, and the correlation between slope and accuracy in the meaningful condition was also significant, $r = -.48$, $p = .003$. The range of slopes for both classes of items was greater for the older adults, as was their variability.

When we partialed out age, the correlation between slopes and accuracy for abstract items was significant, $r = -.32$, $p = .007$, as was the correlation between slopes and accuracy for meaningful items, $r = -.34$, $p = .005$. Overall, the significant negative correlations between slope and accuracy affirm that there is an inverse relationship between information load and STM. Classes of items with high information loads have low STM capacity.

Lastly, to examine how information load influenced STM performance, a repeated measures ANOVA was conducted on accuracy for each level of information load (low, medium, and high). Separate analyses were conducted for each age group and item type. Load type of items was established by evenly dividing each of the classes of items into low (4 items), medium (5 items), and high (4 items), separately for younger and older adults.

Table 7 shows accuracy and slopes for low, medium, and high load types for younger adults. Table 8 shows accuracy and slopes for low, medium, and high load types for older adults. Pairwise contrasts were conducted between low and medium, medium, and high, and low and high load types for each separate analysis using a Bonferroni correction. For meaningful items, younger adults showed a significant main effect of load, $F(2, 70) = 9.47$, $MSE = .007$, $p < .0001$, $\eta^2 = .21$. Low load items ($M = .78$, $SD = .11$) had higher accuracy than medium load items ($M = .72$, $SD = .10$), $p = .03$, whereas medium load items had lower accuracy than high load items ($M = .81$, $SD = .10$), $p < .0001$. Items with low and high loads did not differ in accuracy, $p > .05$, though high load items had the highest accuracy. Older adults showed a similar pattern of results for meaningful items as younger adults, but the main effect of load was marginal $F(2, 68) = 2.65$, $MSE = .007$, $p < .08$, $\eta^2 = .07$. Low load items ($M = .73$, $SD = .14$) had similar but slightly higher accuracy than medium load items ($M = .71$, $SD = .14$), $p = .54$, whereas medium load items had marginally lower accuracy than high load items (*M* = .75, *SD* = .14), *p* = .08. Items with low and high loads did not differ in accuracy, *p* > .05, though high load items had the highest accuracy.

For abstract items, younger adults showed a main effect of load, *F*(2, 70) = 5.49, *MSE* = .008, *p* = .006 , η^2 = .14. Low load items (*M* = .66, *SD* = .10) had higher accuracy than medium load items (*M* = .59, *SD* = .12), *p* = .007, but medium load items were not significantly different from high load items (*M* = .61, *SD* = .11). Items with low and high loads did not differ in accuracy, p > .05. For older adults, there was no main effect of load, *F*(2, 68) = .80, *MSE* = .014, *p* = .45, η^2 = .02.

Both younger and older adults showed a similar pattern for meaningful items, i.e. a decrease in accuracy from low to medium load items, and an increase for high load items. Overall, meaningful items with high loads were the most accurate. For younger and older adults in the abstract condition, the pattern of results differed. For younger adults, there was a significant decrease in accuracy from the low to the medium load items. However, high load items were similar in accuracy to medium load items. For older adults, however, accuracy was similar for all load types.

Discussion

Two findings in the literature led us to predict greater age differences in visual STM for abstract than meaningful items. First, age differences in simple span tasks are greater in the visuospatial than the verbal domain (Myerson et al., 2003; Jenkins et al., 2000), and differential age effects have been found in recognition memory for ‘semantically supported’ items (e.g. line drawings of common objects) versus non-nameable items (e.g. Chinese characters) (Verhaeghen et al., 2000). Second, within the visuospatial domain, studies of younger adults have shown that the complexity of an item is inversely related to STM for that item, i.e. more complex items (items with higher cognitive loads) have smaller spans (Alvarez & Cavanagh, 2004).

To further explore how the perceptual complexity of an item influences STM, we completed additional analyses on accuracy of subsets of items with overlapping loads and items within each class divided into low, medium, and high loads. The first analysis was designed to answer the question: In addition to load, are there characteristics of items that determine their STM performance? We hypothesized that after controlling for information load, abstract items might not show lower accuracy than meaningful items. The second analysis was designed to look for an inverse relationship between cognitive load and STM capacity within each class, for each age group. We had no *a priori* predictions about how this relationship might differ by age.

Congruent with our main prediction, the results showed that abstract items as a class were more difficult to remember than meaningful items. However, differences in STM performance between the two classes of items were equivalent for older and younger adults. Younger adults remembered an average of 3.8 items in the meaningful condition and 3.1 items in the abstract condition, compared to older adults who remembered 3.6 items in the meaningful condition and 2.8 items in the abstract condition.

The analysis on accuracy of subsets of items that had overlapping slopes, supported the hypothesis that information load was a better predictor of STM capacity than item type. The subsets of items consisted of two abstract items whose slopes overlapped with six meaningful items in younger adults. Equating items on information load eliminated item type differences in accuracy. For example, younger adults remembered 3. 8 abstract items compared to 4.0 meaningful items.

We further explored the hypothesis that cognitive load and STM capacity are inversely related, this time within a class. Each class of items was divided into low, medium, and high load items, separately for each age group. Accuracy was then analyzed for the four groups. For meaningful items, the effect of load was significant for younger adults, and marginal for older adults, yet the non-monotonic pattern for meaningful items was similar for both age groups. Medium load items showed the lowest accuracy, and low and high load items had similar but higher accuracy. For abstract items, the pattern of results differed by age. In younger adults, abstract items showed an inverse relationship between load type and accuracy. As load increased for abstract items, accuracy decreased. In older adults, accuracy was similar for items with low, medium, and high load. In support of these findings, correlations between slopes (information load) and accuracy (STM capacity) for both item types reflected an inverse relationship that was significantly stronger for abstract items than meaningful items.

Overall, we found that abstract items were harder to remember than meaningful items. Unlike Experiment 1, age differences in visual STM were not greater for abstract items. In conjunction with evidence from Experiment 1, these results favor the hypothesis that there is an inverse relationship between information load and STM accuracy between classes with differing loads. However, when we looked within classes of items and compared younger and older adult performance, the relationship between information load and STM accuracy was non-monotonic, indicating that, within classes, information load does not seem to be the only determinant of STM performance.

Whereas younger and older adults showed a similar relationship between information load and accuracy for the meaningful class, they showed a different relationship for the abstract class. For both age groups, in the meaningful class, low and high load items had similar accuracy, and medium load items had significantly lower accuracy. This finding perhaps demonstrates the contribution of LTM to STM for items that have greater familiarity, e.g. low and high load items, and may explain why load was not as important a determinant of accuracy for meaningful items. Within the abstract class, younger adults demonstrated the inverse relationship between information load and accuracy that was found between classes, such that low load items had the highest accuracy. Older adults, however, showed decreased sensitivity to changes in the information load of abstract items on accuracy. This is perhaps a reflection of the greater perceptual difficulty of abstract items at encoding (Hartley et al., 2001; Verhaeghen et al., 2000).

CHAPTER VIII

General Discussion

The current study sought to establish greater age differences in the visual domain for abstract than meaningful items, using a visual search task to measure information load and a DMTS task to measure STM accuracy. In order to understand the influence of age, and replicate and extend what is known about the influence of stimulus complexity on visual STM performance, we evaluated the relationship between information load and STM accuracy. Our main hypotheses were that age differences would be greater for abstract than meaningful items in both visual search and STM. We expected an inverse relationship between stimulus complexity and STM in younger adults, and additionally predicted that this relationship might be similar for older adults. In addition, we tested the hypothesis that information load was a better predictor of STM accuracy than item type, by comparing a subset of abstract and meaningful items with overlapping search rates in younger adults. As an additional test of whether information load better explained STM performance than item type, we looked separately within each class and each age group at the relationship between information load and STM accuracy, to see if the same inverse pattern was demonstrated within classes as between classes.

More specifically, the present study of aging had three types of goals, those related to the information load, or complexity of items, those related to visual STM capacity, and those that examined the relationship between information load and STM. In Experiment 1, we used a visual search task to measure and compare the information load of items in two classes,abstract and meaningful, and examined age differences related to information load. We tested the hypothesis that there would be greater age differences in visual search for abstract than meaningful items. In Experiment 2, we used a DMTS task to measure and compare visual STM capacity for those same items, as well as age differences related to visual STM. We predicted that age differences in STM capacity would be greater for abstract than meaningful items. Last, we tested the hypothesis that the information load of abstract and meaningful items was inversely related to capacity in STM. We also looked within the two classes at individual items to see if an inverse relationship between load and capacity was found. Additionally, we tested the hypothesis that information load might not fully account for STM capacity by comparing subsets of abstract and meaningful items on accuracy matched for load.

The predictions about information load and age in Experiment 1 were strongly supported. Abstract items took longer to search than meaningful items. Abstract items showed search rates 2.4 times steeper than meaningful items. As predicted, age differences were also greater in the abstract than the meaningful condition. This pattern of results is comparable to the greater age differences found in conjunction than feature search (Scialfa et al., 1998; Zacks & Zacks, 1993). Older adults show greater difficulty in visual search for perceptually more complex items.

Our hypotheses about visual STM and aging were partially confirmed. In Experiment 2, STM capacity for abstract items was 3.0 items compared to 3.7 for meaningful items. These results parallel those of Alvarez & Cavanagh (2004), who found reduced STM capacity for classes of items with high information loads such as Chinese characters and random polygons. They found capacity estimates from 1.7 items for shaded cubes to 4.4 items for colors, with decreased capacity for abstract items such as random polygons, Chinese characters, and shaded cubes (*M* = 2.1 items) versus meaningful items such as colors, Snodgrass line drawings, and letters (*M* = 3.6 items). Thus information load, as an indicator of complexity, can predict visual STM capacity. Our hypotheses about age differences in visual STM, however, were not supported. Though studies of aging have not been made of visual STM for different types of objects, we had hypothesized that age differences in STM would parallel those in visual search, being greater for abstract than meaningful items. In Experiment 2, the interaction between age and item type was not significant.

The pattern of results for item type from Experiments 1 and 2 fits with two plausible explanations of how more complex items are perceived. The first explanation, advanced by Wheeler & Treisman (2002), is that there are separate, capacity-limited stores in perception for independent features of an item. Independent features of an item need attention in order to be bound as an integrated whole. Items with multiple values of a feature on a single dimension (for instance multiple values of a color or an orientation) cannot be remembered as well as items with a single value of a feature on that dimension. The capacity store for the feature becomes overloaded. For instance, items with multiple line orientations such as the abstract items used in these experiments might have reduced capacity because that dimension (orientation) would become overloaded. Though there are also multiple line orientations in the meaningful stimuli used in this set of experiments, they are less numerous and varied than those of the abstract stimuli.

The second explanation predicts that a minimal representation of an item includes an obligatory set of core features that are always encoded, but that more complex items need to encode details beyond the basic core set to be differentiated (Alvarez & Cavanagh, 2004). This may be one explanation for why abstract items are more difficult to remember than meaningful items. As the visual information required to discriminate between items increases beyond the core set, the maximum number of items that can be stored in memory decreases. For instance, this second explanation might predict that as the similarity of items increased, more information (i.e. more time) might be needed to discriminate the target item. Alternatively, items with two to three distinctive features might be easier to bind because less information would be needed to discriminate that item. Thus, an item's STM capacity on any given trial could be a result of how many features need to be encoded beyond the core set to discriminate it from other items. This second explanation provides a rationale for how perceptually similar items could be more difficult to discriminate (e.g. have lowered STM capacity) and perceptually distinctive items could be easier to discriminate (i.e. have greater STM capacity).

When we looked at the relationship between information load in Experiment 1 and STM accuracy in Experiment 2, the results showed an inverse relationship between information load and STM capacity. Abstract items as a class had higher information loads and lower accuracy than meaningful items as a class. To further explore the influence of information load on STM, we compared subsets of abstract and meaningful items matched for information load on STM accuracy. The results support the hypothesis that information load, not item type, predicts STM accuracy. In other words, information load accounts for the differences in STM accuracy on the two types of items. However, results from further analyses within classes contradicted these findings, lending some credence to the idea that information load may not fully explain STM performance.

When we examined items within a class, separately for each age group, the relationship between information load and accuracy differed by class and age. For younger adults, abstract items within a class showed an inverse relationship. As load increased, accuracy decreased. Unlike younger adults, older adults were not sensitive to increases in information load for abstract items. However, older and younger adults demonstrated a similar pattern of accuracy for meaningful items. For both age groups, in the meaningful class items with medium loads had the lowest accuracy, and items with low and high loads had similar, higher accuracy. This pattern of results could be partially explained by the narrower range in slopes for meaningful items (13.4 to 50.2 for meaningful items versus 22.7 to 97.5 for abstract items), but this does not fully explain why meaningful items with high loads had the highest accuracy.

Unlike abstract items, the perceptual characteristics of meaningful items did not seem to determine how well they were remembered. Additional characteristics of the high load meaningful items may have made them perceptually more difficult in visual search, but equally as distinctive as low load meaningful items in memory. For instance, a meaningful item that is difficult to perceive in a visual search task may be easy to remember because it has familiar visual or semantic content. Overall, this pattern of results suggests that the relationship between information load and STM capacity is not consistently monotonic for meaningful items. Rather, performance accuracy may depend upon representations in LTM that facilitate remembering.

In contrast, it appears that remembering abstract stimuli is more dependent on the perceptual characteristics of the item. An inverse relationship between information load and STM holds for abstract items, at least in younger adults. This hypothesis is supported by an overall stronger negative correlation between abstract slopes and accuracy than meaningful slopes and accuracy. Further, the increased complexity of abstract stimuli may be more dependent than meaningful stimuli upon the discriminability (distinctiveness or similarity), beyond a 'core set', of the features of items in the search array.

An additional question remains. Why were age differences greater for abstract items in visual search, but not in visual STM? Our results suggest that for older adults, age differences in STM storage for visual items are not fully explained by the perceptual demands of the item. The evidence that we obtained from examining the relationship between information load and STM accuracy for items within a class support this picture. Within the abstract class, increasing load did not change accuracy for older adults. Within the meaningful class, increasing load resulted in the same non-monotonic relationship with STM accuracy as younger adults. Although an inverse relationship between information load and STM accuracy was demonstrated between classes for both younger and older adults, it is not evident that the perceptual complexity of an item solely delimits STM performance in older adults.

In summary, Experiments 1 and 2 support the hypothesis that there is an inverse relationship between information load and STM capacity, with some constraints. There was little between-class evidence to support the hypothesis that item type predicted STM capacity above and beyond information load, though when we looked within classes of items, meaningful items showed a unique pattern of performance. Contrary to prediction, meaningful items with high loads had similar accuracy to meaningful items with low loads. This suggests that the meaningfulness of an item may play a role in STM performance above and beyond information load. On the surface, this statement contradicts the between-class comparison, yet reflects the analysis of items within a class where factors other than information load such as semantic content, similarity, or distinctiveness may be operating (see Hartley et al., 2001 and Verhaeghen et al., 2000 for explanations of item-related dissociations). Although older adults showed the same pattern of performance in STM for meaningful items as younger adults, age differences in visual search related to the perceptual characteristics of an item did not fully explain age differences in STM performance. Within the abstract class, unlike younger adults, older adults did not show an inverse pattern of performance. This suggests that the semantic characteristics of meaningful items that enhance memory performance are more age-invariant than the perceptual characteristics of abstract items. Further, age differences in processing stimuli without meaning appear to be greater on a task that measures selective attention and perception than visual STM.

Table 1

Characteristics of Older and Younger Adults

	Younger adults		Older adults	
Descriptive Measure	M *(SD)*	*Range*	M *(SD)*	*Range*
Age	18.7 (1.2)	17-23	71.5 (7.4)	60-84
AmNart Vocabulary (max = 45)	30.6 (4.6)	20-38	38.8 (4.7)	25-45
Mini-Mental State Exam (max = 30)	--	--	29.2 (1.0)	27-30
Beck Depression Inventory (max = 63)	6.3 (3.7)	2-18	4.2 (3.9)	0-17
Beck Anxiety Inventory (max = 63)	4.9 (3.8)	0-15	2.6 (3.6)	0-14

Note. The dash indicates that MMSE scores were not available. max = maximum.

Table 2

A Subset of Abstract and Meaningful Objects with Overlapping Reaction Times from Pilot Tests

Abstract			Meaningful		
Item	M	SD	Item	M	SD
abst12	693.1	72.9	lamp	613.3	108.7
abst13	750.6	82.0	crown	655.8	268.8
abst2	763.2	103.5	hat	682.0	156.3
abst7	880.6	174.0	cake	689.4	117.3
abst3	903.6	160.7	drum	730.8	163.4
Mean	798.2	118.62	Mean	674.3	162.9

Note. The subset of both abstract and meaningful object reaction times were consistent across Pilot Tests B2 (N=8), B2A (N=5), and B2B (N=4).

Table 3

Reaction Times for Younger and Older Adults from the Visual Search Task in Experiment 1

Item type and array size		Younger Adults M	Younger Adults SD	Older Adults M	Older Adults SD
Abstract	4 items	764.2	141.8	1003.3	152.5
	8 items	1032.3	202.8	1390.5	326.5
	12 items	1279.9	263.1	1723.6	408.0
	Mean	1025.5	202.6	1372.5	295.7
Meaningful	4 items	618.6	125.8	727.3	128.9
	8 items	739.0	166.2	853.3	200.7
	12 items	866.4	219.6	993.6	187.2
	Mean	741.3	170.5	858.1	172.3

Table 4

Slopes (visual search rate) for Younger and Older Adults from the Visual Search Task in Experiment 1

	Younger Adults		Older Adults	
Item type	M	SD	M	SD
Abstract	64.47	22.19	90.04	35.99
Meaningful	30.98	14.89	33.29	15.78

Table 5

Slopes (visual search rate) and Accuracy (proportion correct) for Overlapping Subsets

Meaningful					Abstract				
	Slope		Accuracy			Slope		Accuracy	
Item	M	SD	M	SD	Item	M	SD	M	SD
clock	19.50	11.87	0.74	0.17	abst13	22.75	12.61	0.69	0.21
bed	23.84	10.62	0.82	0.18	abst12	44.63	16.33	0.83	0.20
lamp	41.01	25.43	0.85	0.15					
cake	41.15	18.89	0.85	0.16					
hat	43.30	22.20	0.78	0.19					
drum	50.17	15.45	0.75	0.19					
Mean	36.50	17.41	0.79	0.17		33.69	14.47	0.76	.21

Note. Means for the overlapping subsets did not differ, $t(70) = 1.27$, p=.21

Table 6

Accuracy (proportion correct) for younger and older adults for the DMTS task in Experiment 2

	Younger Adults		Older Adults	
Item type	*M*	*SD*	*M*	*SD*
Abstract	0.62	0.08	0.56	0.07
Meaningful	0.76	0.07	0.72	0.12

Table 7

Slopes (visual search rate) and Accuracy (proportion correct) for Abstract and Meaningful Items with Low, Medium, and High Loads in Younger Adults

	Meaningful					Abstract				
	Slope			Accuracy		Slope			Accuracy	
Load	Item	M	SD	M	SD	Item	M	SD	M	SD
Low	sun	13.40	2.43	0.80	0.17	abst13	22.75	12.61	0.69	0.21
	clock	19.50	11.87	0.74	0.17	abst12	44.63	16.33	0.83	0.20
	bed	23.84	10.62	0.82	0.18	abst7	57.37	20.43	0.53	0.22
	heart	26.01	16.00	0.76	0.19	abst2	58.28	17.86	0.58	0.21
	Mean	20.69	10.23	0.78	0.18	Mean	45.76	16.81	0.66	0.21
Medium	skirt	28.77	9.26	0.72	0.19	abst9	59.37	27.48	0.62	0.25
	book	29.93	16.24	0.75	0.16	abst5	63.56	11.49	0.62	0.20
	onion	30.40	15.67	0.67	0.16	abst1	66.84	32.94	0.51	0.22
	crown	33.02	15.42	0.74	0.20	abst8	69.36	34.06	0.66	0.22
	glass	34.04	10.99	0.72	0.19	abst4	70.64	18.5	0.53	0.21
	Mean	31.23	13.52	0.72	0.18	Mean	65.95	24.89	0.59	0.22
High	lamp	41.01	25.43	0.85	0.15	abst3	76.43	26.82	0.64	0.21
	cake	41.15	18.89	0.85	0.16	abst10	79.06	27.49	0.56	0.24
	hat	43.30	22.20	0.78	0.19	abst11	85.51	27.48	0.62	0.19
	drum	50.17	15.45	0.75	0.19	abst6	97.48	24.67	0.63	0.24
	Mean	43.91	20.49	0.81	0.17	Mean	84.62	26.62	0.61	0.22

Table 8

Slopes (visual search rate) and Accuracy (proportion correct) for Abstract and Meaningful Items with Low, Medium, and High Loads in Older Adults

	Meaningful					Abstract				
	Slope			Accuracy		Slope			Accuracy	
Load	Item	M	SD	M	SD	Item	M	SD	M	SD
Low	sun	8.10	-1.67	0.76	0.19	abst13	41.05	25.59	0.65	0.21
	heart	20.00	4.98	0.63	0.25	abst7	72.88	56.73	0.57	0.26
	bed	20.82	4.14	0.83	0.19	abst9	73.78	36.80	0.54	0.23
	crown	23.41	6.15	0.70	0.24	abst2	80.49	35.31	0.43	0.19
	Mean	18.08	3.40	0.73	0.22	Mean	67.05	38.61	0.55	0.22
Medium	clock	26.21	16.02	0.75	0.23	abst1	83.86	35.96	0.49	0.21
	book	30.01	11.43	0.66	0.20	abst3	84.70	40.79	0.57	0.24
	skirt	31.15	17.45	0.70	0.20	abst12	88.73	49.72	0.70	0.25
	onion	38.40	13.64	0.61	0.23	abst4	93.92	37.49	0.56	0.29
	hat	41.74	12.09	0.81	0.19	abst10	104.47	47.89	0.58	0.18
	Mean	33.50	14.13	0.71	0.21	Mean	91.14	42.37	0.58	0.24
High	lamp	46.27	13.33	0.75	0.22	abst11	105.30	49.93	0.54	0.25
	cake	46.68	11.59	0.81	0.21	abst5	115.32	58.77	0.55	0.20
	glass	48.68	12.25	0.72	0.22	abst8	116.88	64.12	0.54	0.25
	drum	60.75	21.58	0.73	0.21	abst6	128.78	43.43	0.58	0.20
	Mean	50.60	14.69	0.75	0.22	Mean	116.57	54.06	0.55	0.23

Appendix I

AFTER TESTING: **Call Again:**
Excluded? State reason:
Additional Session Comments:

Name: ____ Contact Date __________________
Phone Number: ______________________________ Phone interviewer ________________
How recruited ___________________
Date and time scheduled _______________________ Experimenter ____________________
Name of experiment recruiting for, if applicable _______________________________________

I would like to ask you a few questions about yourself. Most of them are related to your health, to make sure that you meet the requirements for these studies. Shall we go ahead with those?

1. **How old are you?** _______________ **Date of birth:** ______________
2. **Is English your native language?** **yes** **no**
   If not, explain.
3. **Gender** **Female** **Male**
4. **How far did you go in school?** ____________________________
5. **Do you have any vision problems that are not corrected by wearing glasses?** **yes** **no**
   If yes, describe. (Can you read normally?)
6. **Are you color blind?** **yes** **no**
7. **Do you have any problems with your hearing?** **yes** **no**
   If yes, describe.

8a. How would you rate your overall health *in the past year*? *Would you say that it is ....*

excellent 4 ______ **fair 2** _______
good 3 ______ **poor 1** _______

8b. How would you rate your overall health *at this time*? *Would you say that it is ....*

excellent 4 ______ **fair 2** _______
good 3 ______ **poor 1** _______

(Criterion for Hartman lab: 'good' or 'excellent' for Question 8a; for Bayen lab: 'good' or 'excellent' for Question 8b.)

The next few questions relate to specific types of health problems you may have had. As I ask each question, please tell me whether you have ever had that particular kind of problem. If you don't feel comfortable answering the question, just let me know.
(Note: 'Yes' responses to questions 9 – 21 result in exclusion, except where otherwise indicated.)

9. **Have you ever had any form of cancer?** **yes** **no**
   If yes, please explain.
   If yes, have you had chemotherapy treatment?
   (For Bayen lab, exclude for chemotherapy. For cancer without chemotherapy, decision to be made on case by case basis. For Hartman lab, exclude only for chemotherapy within the past year.)
10. **Do you have any history of heart disease?** **yes** **no**
    If yes: please explain.
11. **Have you ever had a heart attack?** **yes** **no**
    (For Bayen lab, exclude for heart attack, but decisions for other types of heart disease to be made on case by case basis. For Hartman lab, exclude for heart attack or any type of heart disease.)
12. **Do you have diabetes?** **yes** **no**
    If yes, what type? (If type I, exclude for Hartman and Bayen Lab)
13. **Do you have emphysema?** **yes** **no**
    Do you have any other type of lung disease? **yes** **no**
    If yes, please explain. (For Bayen lab, exclude for emphysema but decisions for other types of lung disease to be made on case by case basis. For Hartman lab, exclude for any lung disease.)

14. Do you have any kidney disease? **yes** **no**
If yes, please explain.
(For Hartman lab, exclude if yes. For Bayen lab, decision to be made on case by case basis**)**

15. Have you ever had, or are you being treated for, high blood pressure? **yes** **no**
If yes, is it well controlled by diet or medication? yes no
Criterion for normal or well controlled BP: not over 140.
(Exclude for Hartman lab if not well controlled. For Bayen lab, no exclusion.)

16. Have you ever had
a) a stroke or TIA (transient ischemic attack; small stroke) ? **yes** **no**
b) a brain tumor? **yes** **no**
c) a seizure (fits, convulsions, epilepsy)? **yes** **no**
d) a head injury (concussions) such as from a fall or car accident? How many? **yes** **no**
Criterion: less than 3 head injuries
If yes, and less than 3, did you lose consciousness? yes no
For how long? (Criterion: total time must be less than 10 minutes)

17. Do you have Parkinson's Disease? **yes** **no**

18. Do you have any (other) neurological problems? **yes** **no**
If so, describe.
'Yes' responses may or may not result in exclusion. To be decided on case by case basis.

19. Have you been hospitalized for emotional problems in the past 5 years? **yes** **no**

20. Are you currently taking medications for mental or emotional problems? **yes** **no**

21. Are you currently taking medication to help you sleep? **yes** **no**
If yes, how often?
(For Hartman lab: If taken on a regular basis, exclude. If taken occasionally, then include only if it is possible to schedule a testing session at a time when the individual has not taken sleeping medication for the two preceding days. For Bayen lab, no exclusion for sleep meds.)

22. What medications, if any, do you take (both prescription and over the counter), and what do you use the medication for?

Name of medication	Reason for taking medication
____________________	____
____________________	____
____________________	____
____________________	____
____________________	____

Criterion: Exclude if any of these drugs have known cognitive effects.

23. Have you had any major health problems not previously mentioned? **yes** **no**
If yes, describe.____
Criteria for exclusion: To be decided on case by case basis.

Final assessment: Eligible for participation **Yes** **No** **Not sure**
If eligible and a time is scheduled, write in the appointment on top of page 1.
If 'not sure,' tell the person that you will need to verify the individual's eligibility and call them back.
If participant wants to participate at the same time as another participant, ask for:
Name of companion: ____________________________
Note: Tell this participant that you'll have to speak with the other person to be sure s/he qualifies (either for health reasons or because of participation in an earlier version of the current study).

23. Transportation: Car Bus Walking Bicycle Other________________

24. Where to meet the participants: Parking area Lobby Other _______________

Note: Please pass on information to other lab if an individual fails criteria for your lab but meets those of the other lab.

Appendix II

AmNart Pronunciation Guide & Scoring Sheet ID#______ Y/O Date: ________

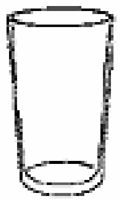
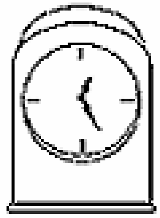
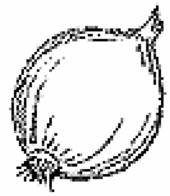
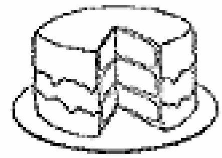
Instructions for Administration: *Participant is instructed to read each word aloud. They can take up to 10 seconds to respond and should be encouraged to guess if they are unsure. When a subject gives more than one pronunciation, the last pronunciation is evaluated for accuracy. Testing is discontinued after 10 consecutive errors are made. Tally the number of correct pronunciations.*

Correct?

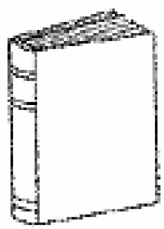
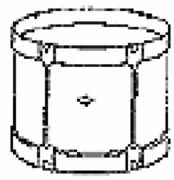
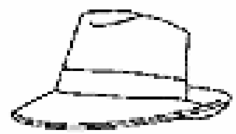
	1.	ACHE – ak
	2.	AISLE – il
	3.	CAPON – ka pon *(KAY pon)*
	4.	DEBT – det
	5.	CHORD – kord
	6.	HEIR – ar *(air)*
	7.	DENY – di-ni
	8.	BOUQUET– bo ka *(bow kay* or *boo kay)*
	9.	CAPRICE – ka –pres *(long 'e' short 's')*
	10.	GAUGE – gaj
	11.	WORSTED – woos tid *(if participant says "worse tid" ask if they can give another pronunciation)*
	12.	DEPOT – de po *(deppo* or *dee po)*
	13.	NAUSEA – no ze-a *(there are four pronunciations listed for this word - to hear them go to Merriam Webster online)*
	14.	NAÏVE – na-ev
	15.	SUBTLE – sut'l
	16.	PUGILIST – pyoo ja list
	17.	FETAL – fet'l
	18.	BLATANT – blat'nt
	19.	PLACEBO – pla –se bo *(pla see bow – if participant gives Italian pronunciation – plah chay bow – ask for English one)*
	20.	HIATUS – hi-a ta s
	21.	SIMILE – sim a –le
	22.	MERINGUE – ma –rang
	23.	SIEVE – siv
	24.	CHASSIS – shas e *(or chass ee)*
	25.	CELLIST – chel ist
	26.	ALGAE – al je
	27.	SUPERFLUOUS – soo-pur floo-a s *(suh perfloo us)*
	28.	CHAMOIS – sham e *(if participant gives French pronunciation – sham wah – ask for English one)*
	29.	THYME – tim *(time)*
	30.	APROPOS – ap ra –po
	31.	VIRULENT – vir ya la nt *(VEER uh lnt)*
	32.	ZEALOT – zel at
	33.	FAÇADE – fa –sad
	34.	CABAL – ka –bal *(ka BALL* or *kab AL – Al like the name)*
	35.	ABSTEMIOUS – ab-ste me-as
	36.	DÉTENTE – da-taNT
	37.	SCION – si an
	38.	PAPYRUS – pa –pi ras
	39.	QUADRUPED – kwod ra –ped
	40.	PRELATE – prel it
	41.	EPITOME – i-pit a –me
	42.	BEATIFY – be-at a –fi
	43.	HYPERBOLE – hi-pur ba le
	44.	IMBROGLIO – im-brol yo
	45.	SYNCOPE – sing ka –pe

Appendix III

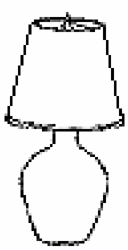
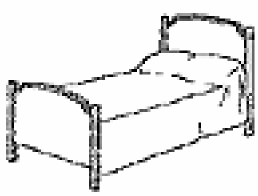
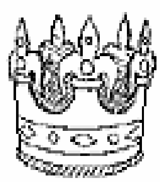
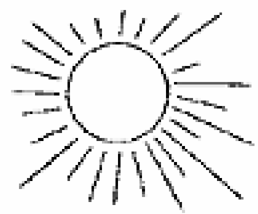
Meaningful Items

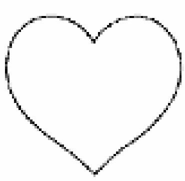
glass	clock	onion	cake

skirt	book	drum	hat

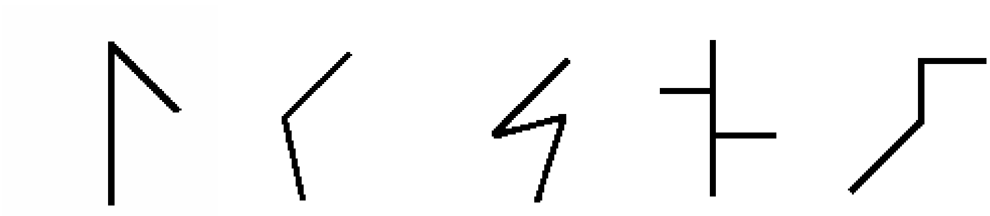
lamp	bed	crown	sun



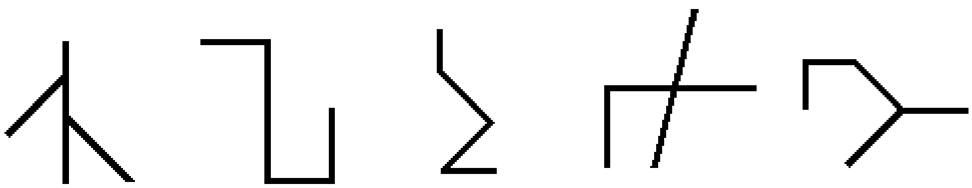
heart

Appendix IV

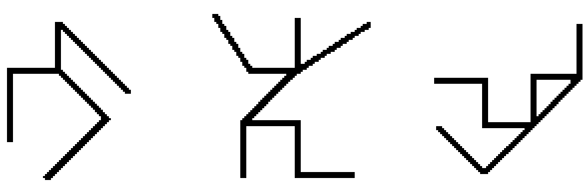
Abstract Items



abst1	abst2	abst3	abst4	abst5



abst6	abst7	abst8	abst9	abst10



abst11	abst12	abst13		

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